EFFECTS OF MARINE MUD UPON THE AEROBIC DECOMPOSITION OF PLANKTON MATERIALS [1]

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A number of recent investigations of bacterial activity in natural fresh and salt waters, in soils, and in muds strongly suggest that the rates of bacterial decomposition in these sites may be modified by finely divided and colloidal inorganic materials.

It is noted that marine bacteria are carried from suspension by settling marine and salt lake muds. To an undetermined degree encapsulated clumps, slime masses, and bacterial chains are mechanically occluded in the precipitating material, but the ratio of cells removed bears a relation to the electrical charges borne by the muds and bacteria characteristic of physical adsorption (3, 4, 5). Terrestrial soils also carry down adhering bacteria from suspensions. The degree of concentration may be varied by altering the charge on the soil particles (3).

Many marine and fresh water bacteria are sessile in habit, and it has been observed that the amount of bacterial substance in the attached films that these organisms form greatly exceeds the concentration in the surrounding water (6, 7). When the ratio of surface/volume in stored sea water is increased, the bacterial numbers rise and various physiological processes are stimulated. It has been suggested that the higher biological oxygen consumption associated with the increase in surface may be related to the adsorption and concentration of soluble organic materials and bacterial enzymes upon the enclosing surfaces (8).

Soluble and finely divided organic materials are themselves adsorbed on fresh water muds. River silts carry organic matter from muddy water to the bottom as they settle (2). From comparative studies of the biological oxygen demand characteristics, it appears that the organic matter in the silts breaks down at a much lower rate than that of the water from which they settled.

The experiments reported in this paper are attempts to discover if

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marine muds affect the rates at which plankton materials undergo aerobic decomposition in the superficial layers of the sea bottom. Studies on the breakdown of sewage sludges indicate that aerobic conditions may prevail in the upper centimeter of the active mass, and it is probable that this also applies to the more flocculent surface muds receiving freshly settled debris from the sea (1).

Surveys of the distribution of organic matter and bacteria in marine muds indicate that biological changes go on relatively slowly in the sea bottom. It was thought, initially, that the adsorption of organic matter on the materials of the mud might be a significant factor in limiting bacterial activity.

Experiments on the Adsorption of Plankton Materials by Marine Mud

Materials

The mud used in these experiments was prepared from a series of short cores, 4 to 6 inches deep, taken from a station in the Gulf of Maine (N. 42° 25′, W. 70° 35′) at a depth of 100 meters. It had been stored for a year in the laboratory at room temperatures. A week before the work began the material was mixed with "aged" sea water and repeatedly suspended to remove heavy sand, fine gravel, shell particles, and other large fragments. A final suspension was made and aerated gently for three days. This was allowed to set—the heavy fraction separating within thirty seconds was discarded, and the remainder drawn off for use. The gross analysis of this mud was as follows:

Loss of weight on drying at 105° C. (corrected for salt content)	71.0 per cent
Loss of weight on ignition (on dry weight, salt-free basis)	11.5 per cent
Total nitrogen (on dry weight, salt-free basis)	0.20 per cent
Content of nitrogen per ml. wet mud as used in the experiments	0.70 mgm./ml.

Fresh plankton suspensions were prepared for each experiment from tows taken in Vineyard Sound (collected with No. 20 silk net, chilled, and prepared within four hours). This material consisted predominantly of species of *Rhizosolenia*. The tow was ground and filtered by suction through washed No. 52 Whatman filter paper. Nitrogen content of the extract was determined by micro-Kjeldahl, and convenient sea-water dilutions were prepared from the concentrated stock.

Determination of Adsorption

Varying concentrations of mud and plankton extract were stirred together on a gently rocking shaker for different intervals of time. Samples were withdrawn and nitrogen analyses made on aliquots of the mixture. Fifty-milliliter quantities of the mixture were placed in a clinical centrifuge and whirled until clear. Separate nitrogen determinations were made upon the mixture, upon the supernatant, and upon the centrifugate. The adsorption of plankton extract on mud in various

TABLE I

Adsorption of Nitrogenous Materials by Marine Mud

A. Plankton Extract

Concentration of N in extract 0.60 mg./ml.
Concentration of N in mud 0.70 mg./ml.

Ratio of mud to extract	N in supernatant after centrifuging (three-hour mixing)	N adsorbed by mud in three hours	N in supernatant after centrifuging (twelve-hour mixing)	N adsorbed by mud in twelve hours
	mg./ml.	*per cent*	*mg./ml.*	*per cent*
1 : 5	0.36	40	0.34	43
1 : 2.5			0.31	49
1 : 1	0.23	61	0.20	67
2 : 1	0.12	80	0.11	82

B. Peptone Solution

Concentration of N in solution 0.55 mg./ml.
Concentration of N in mud 0.70 mg./ml.

Ratio of mud to solution	N in supernatant after centrifuging (twelve-hour mixing)			N adsorbed by mud in twelve hours
	mg./ml.			*per cent*
1 : 25	0.42			23
1 : 2	0.13			77

mixtures under these conditions is demonstrated in the data given in Table I.

It is evident from this that the nitrogen-bearing fraction of plankton extracts are strongly adsorbed on marine mud. The concentrations involved in these experiments are several thousand times as high as those occurring in sea water but fall within the ranges that occur in marine muds.

Soluble materials such as plankton extract and peptone are readily

adsorbed at room temperatures, but bacterial digests of the same material are not removed to a comparable degree. In an experiment with a dense suspension of mixed bacteria grown in plankton extract, only 10 per cent of the nitrogen was adsorbed from suspension by mud stirred for 12 hours and centrifuged under conditions comparable to those applying in the other experiments. Microscopic examination of the mud thrown down showed the bacteria moving freely through spaces between particles—the centrifugate remained cloudy with motile bacteria.

Experiments on the Effect of Mud on Rates of Aerobic Decomposition

Breakdown of Particulate Plankton

Previous experiments on the rates of decomposition of organic matter in marine muds have been quantitatively unsatisfactory because of the technical limitations of the standard biological oxygen demand method. In these experiments the difficulties were eliminated by using a series of respirometers. The apparatus was designed by the author for the direct measurement of oxygen consumption of such organic matter rich systems as grossly polluted waters, sewage sludges, and manured soils. A description of their design and applications will be published in the near future.

In the first experiment the respirometers were filled with mixtures of mud and finely ground, unfiltered plankton. Duplicate respirometers were used for each mixture and filled as follows:

Set A—4 units mud in 200 ml. aged sea water
Set B—2 units mud, 1 unit plankton in 200 ml. aged sea water
Set C—1 unit mud, 2 units plankton in 200 ml. aged sea water
Set D—4 units plankton in 200 ml. aged sea water

Carbon analyses were not available for the plankton material, but satisfactory approximations may be made from the nitrogen determinations. Assuming a C/N ratio of 10:1 for the organic matter of the mud, the organic carbon value of the unit of mud is about 3.5 mgm. If a C/N ratio of 8:1 is taken for the plankton, the value of the plankton unit in terms of organic carbon is 2.4 mgm.

During the five-day term of this experiment the temperature was 23° C. ± 0.5° C.

The oxygen consumption of the various mixtures is plotted against time in Fig. 1.

Greatest irregularities occur in the duplicate samples of mud—possibly through the accidental inclusion of organic particles. It can be

assumed that the oxygen consumed in this interval was utilized in the biological oxidation of the organic carbon in the plankton material. On this basis a little over 50 per cent of the plankton carbon was oxidized during the five days of activity. The organic matter of the mud is more stable—in the same interval about 7 per cent of this carbon underwent oxidation.

In the mud and plankton mixtures the amounts of organic carbon oxidized to carbon dioxide are not significantly different at any time from the values that would be estimated from the consumptions of the separate

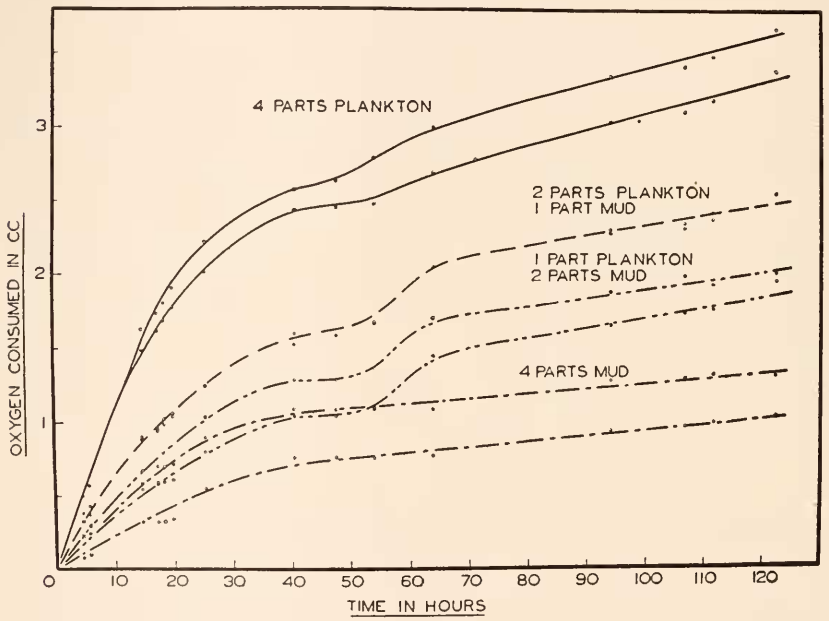

Fig. 1. Biological oxygen consumption in sea water suspensions of mud (lower set of curves), of ground plankton (upper curves), and of mixtures of mud and plankton (intermediate curves).

components. There is a slight increase in the proportion of carbon oxidized in the mixtures, but this effect is most pronounced in the lower concentration of plankton and may be related to the dilution effect observed in the third experiment.

Breakdown of Plankton Extract

A second experiment was prepared, using plankton extract instead of fine, particulate plankton. Mud, plankton-extract, and sea water were placed in sets of duplicate respirometers as follows:

Set A—4 units mud in 200 ml. aged sea water
Set B—2 units mud, 1 unit plankton, 200 ml. sea water
Set C—1 unit mud, 2 units plankton, 200 ml. sea water
Set D—4 units plankton in 200 ml. sea water

The nitrogen values of the mud and plankton units in the charges were adjusted to equal those of the first experiment. During the five days of activity the temperature ranged about 23.5° C. ± 0.5° C.

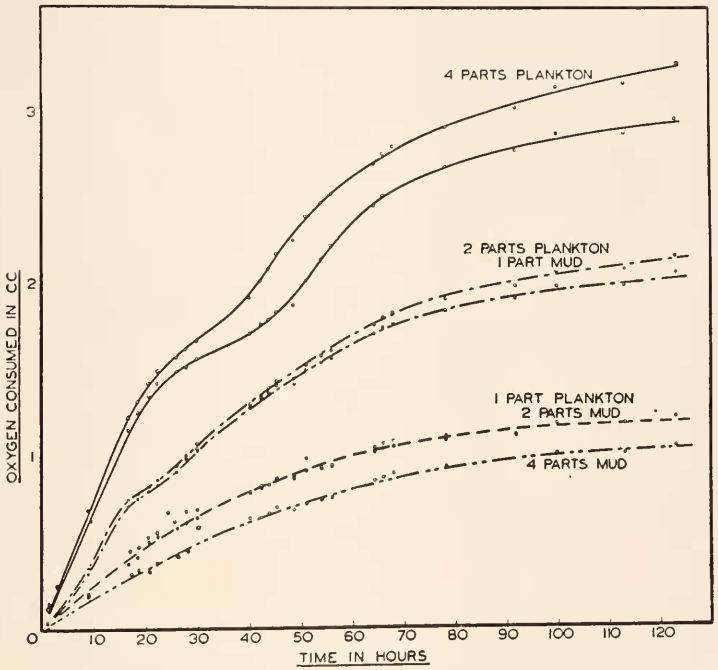

Fig. 2. Biological oxygen consumption of sea water suspensions of mud, plankton extract, and of mixtures of mud and plankton extract.

At the end of the second experiment approximately 45 per cent of the plankton carbon had been oxidized and between 6 and 7 per cent of the organic carbon in the mud. Very slightly more oxygen was consumed in the mixtures than would be calculated, but this difference is not significant when the greater efficiency of breakdown in the more dilute suspensions (Exp. 3) is considered.

Effect of Concentration on Decomposition in Mud

In the final experiment an attempt was made to discover what effect might be expected in rich mixtures of mud and plankton as compared

with the relatively dilute suspensions of mud and plankton used in the first two experiments. The respirometers were loaded in the following manner:

Set A—4 units mud (no added sea water)
Set B—2 units plankton extract, 2 units mud
Set C—2 units plankton extract, 2 units mud, 100 ml. aged sea water
Set D—4 units plankton extract (no added sea water)

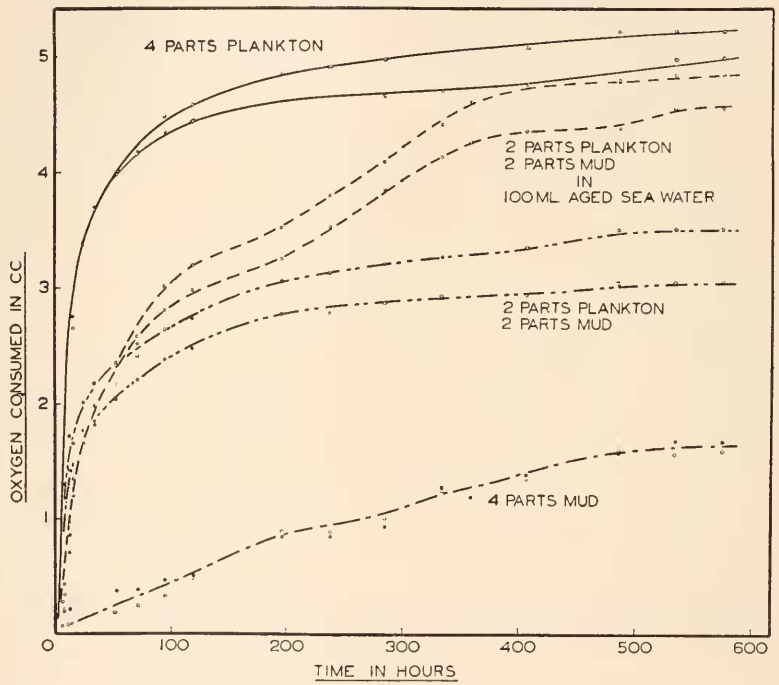

Fig. 3. Biological oxygen consumption concentrated mud, plankton extract, mixtures of plankton extract and mud, and of a sea water suspension of mud and plankton extract.

Although the rate of oxygen uptake had markedly decreased by the end of five days at 23.0° C. ± 0.5° C., the experiment was continued for 24 days.

At the end of this time 75 per cent of the organic carbon in the plankton extract had been oxidized and about 16 per cent of that in the mud. The undiluted mixture of mud and plankton consumed oxygen at a rate practically equal to that anticipated from the rates of consumption in the separate mud and plankton cultures.

The oxygen demand curve of the mud and plankton mixture diluted with 100 ml. of sea water is markedly different, however. It indicates a more rapid consumption of oxygen during the first hundred hours and a prolonged demand during the next three hundred hours. The oxygen consumed at the end of the active period—300 hours—is about 50 per cent greater than that taken up by the concentrated mud and plankton mixture. This effect of dilution is not related to the oxygen consumption of the added, aged sea water. Repeated determinations were made on the water alone and in no case did the oxygen demand of five-day intervals exceed 0.2 ml. per liter.

Discussion

It appears from these experiments that marine muds have little if any direct effect upon the rates at which readily decomposed organic materials that may be mixed with them undergo aerobic decomposition.

The fact that marine muds adsorb nitrogenous organic materials may be significant, however, in determining the normal course of their breakdown. Soluble organic matter released by autolytic or digestive processes may be localized in the mud where anaerobic changes and low temperatures prevail.

It is unlikely that silts perform transport functions in the sea as they do in the slow-flowing parts of silt-laden rivers, but by slowing down the rates of diffusion and maintaining relatively high local concentrations, muds may lower the effective rate of bacterial decomposition in the bottom.

Summary

1. Marine muds strongly adsorb soluble nitrogenous organic materials of plankton origin.

2. Muds exert little if any direct effect upon the rates or efficiency of anaerobic bacterial decomposition of plankton materials.

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